

# ENTRY, DESCENT AND LANDING FOR MARS SAMPLE RETURN: THE EUROPEAN TECHNOLOGY DEVELOPMENT AND DEMONSTRATION APPROACH

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## ABSTRACT

The Mars Sample Return (MSR) mission represents one of the major milestones in the exploration of Mars and of the solar system in general. Within the European Space Exploration Programme: Aurora, the MSR mission represents a key driver of technologies and capabilities relevant to other areas of exploration. Described in this paper is the approach to landing system development being pursued within the Aurora Core Programme, and the links with the 'NEXT' mission opportunity.

## 1. INTRODUCTION

Today, with the early preparatory phases of the Aurora Programme complete, Europe has built the foundations of a healthy and robust future in exploration. Combined with the progress made in the maturation of the ExoMars mission, a steady series of advancements have been made across an even broader range of exploration capabilities and technologies, from those required for future human exploration to those more related to advanced robotic exploration of the solar system.

Despite the progresses which have been made, work still remains and will likely always remain, to prepare for the exploration missions of the future, whether these be near-medium term robotic missions, or longer-term human exploration. As identified in the early days of Aurora, the Mars Sample Return (MSR) mission represents a major milestone in the exploration of Mars and the solar system at large: both in terms of scientific understanding of the history of life and the environment of Mars, as well as the technologies and capabilities required to perform this difficult and challenging mission.

MSR represents one of the major European goals with respect to exploration, and it is the approach of ESA within the Aurora Programme to prepare for a significant European participation in what is expected to be a mission of broad international cooperation. This preparatory effort, being coordinated within the Core Programme of Aurora, consists of several key elements such as the identification and refinement of key MSR requirements, the development of technologies which

might satisfy these requirements, and the investigation of potential opportunities to demonstrate such technologies and capabilities.

## 2. MARS SAMPLE RETURN: CONTEXT IN AURORA

Since the early elaboration of the original Aurora roadmap there have been many shifts in the landscape of space exploration at international level, with the NASA Vision, the situation of the ISS, the evolving space exploration plans of other partners, and new discoveries made by ongoing missions. Despite these changes, and the resulting evolution of the European Aurora roadmap, MSR has remained a high priority in the Programme. This is due in many ways to the key step it represents in the exploration of Mars and in the search for evidence of extinct or extant life, but also in the technologies and capabilities it employs.

As a medium-long term goal within Aurora, MSR represents a focus for many developments which might 1) lead to a strategic European contribution to this mission, and 2) be of key significance in enabling European leadership of, or participation to, other exploration missions. This role is more clearly visible in the ongoing development of technologies within Aurora, which in many cases use MSR as a mission driver.

The MSR mission itself has been the subject of a great deal of investigation within the Aurora Programme, through a first internal Concurrent Design Facility (CDF) study and subsequent industrial Phase A1 level work. Most recently the MSR Phase A2, ongoing with Thales-Alenia-Space as Prime, has performed a further refinement of the mission design; addressing trade-offs which remained open and identifying in detail some of the critical mission elements which should be investigated in the future steps.

Today, the current European baseline MSR mission scenario employs two Ariane-5 launches to send separately two different mission assemblies to Mars. The first (Assy #1) includes an orbiter, for communications support to the mission, as well as the

Earth Return Capsule (ERC) and return stage attached to the orbiter. The second element (Assy #2) is a carrier plus a descent module (DM). The DM, consisting of a surface platform and the Mars Ascent Vehicle (MAV), must carry out the critical EDL sequence. The currently envisioned launch dates for these two assemblies is 2019 for Assy #1, and 2021 for Assy #2.

### **3. ENTRY, DESCENT AND LANDING FOR MSR**

The MSR mission is challenging in many respects, however one of the most difficult aspects is the entry, descent and landing (EDL) sequence. This is due to a particularly tough set of requirements which place a great demand on the EDL system.

#### **3.1 Landing Requirements**

One of the first and most apparent requirements for the MSR EDL system is the high landed mass (in excess of 1000kg), due largely to the fact that not only does the surface platform have to embark the equipment required to carry out the surface operations, but also the Mars Ascent Vehicle (MAV) to carry the sample container to Mars orbit. This very high landed mass represents a substantial increase over and above past, ongoing and future near-term missions.

The size and sensitivity of the surface platform implies that the landing itself must be ‘soft’ in nature, i.e. with the landing loads limited below a certain value (e.g. < 6g). This is in contrast to the semi-hard landings provided by bouncing or vented air-bag systems.

With so much being invested in the return of Martian samples, it is of key importance to be able to target landing sites with a high degree of accuracy. Related to this is the requirement to be able to land safely and to avoid surface hazards which might only be detected during the descent phase itself.

Lastly and perhaps most importantly due to the communications delay time between Earth and Mars, is the need to perform the entire EDL sequence, satisfying all of the above requirements, entirely autonomously. This implies detecting and reacting to perturbations during the entry and descent which might affect the accuracy and taking action when necessary to avoid surface hazards.

#### **3.2 EDL Architecture**

After several iterations on the design of the EDL sequence and the selection of various options, a baseline of the descent phase is now in place. Of course this is still open to refinement in later mission study phases, however the main elements help to illustrate both how the tough requirements of the mission are satisfied and explain the preparations underway to develop what is needed – which are described in more detail shortly.

The EDL sequence begins with the separation of the DM from its carrier and the coast to the entry point interface. At an altitude above Mars of approximately 125km and a velocity of almost 6km/s, the guided entry phase begins. This guided entry is necessary in order to achieve the tough landing accuracy requirement of 10km. Using thrusters to change the bank angle of the DM, the entry phase is controlled to the level of accuracy required by the mission. The hypersonic entry phase ends at an altitude of approximately 10km with the jettison of the backshell and deployment of the parachute. It is also at this stage that the landing gear is deployed and the navigation sensors become active – up until this point the GNC system relies on the on-board IMUs.

Between an altitude of around 10km to 4km, the parachute arrests the DM’s velocity from 500m/s to 50m/s, at which point the parachute is jettisoned and the propulsive descent phase begins. The propulsive phase follows a gravity turn profile in order to put the navigation sensors in their nominal operating state with respect to the ground. During the descent the navigation sensors, which at this point can include LIDAR and/or visual camera (the final GNC system may employ both for robustness), perform measurements of the surface to determine slope characteristics, roughness and the presence of shadows. These are all used to search for a safe landing site, and if necessary pilot to a newly selected safe landing site. At around 150m there is no longer the capability to select a ‘new’ safe landing site, and the approach phase begins. During this final approach phase the navigation sensors and the GNC as a whole may still command the DM to avoid surface hazards such as boulders in the vicinity of the landing site. From 10m, the DM performs its terminal descent, commanding main engine cut-off at sufficient time to guarantee acceptable landing loads at touchdown.

When considering the developments necessary in order to be able to design an EDL system to implement the architecture described above, there are several aspects to be taken into account. While the entry phase and the parachute descent are critical to the architecture, the first steps in the development of these are inherently necessary in the frame of the ExoMars mission, which will ultimately provide a strong experience in these specific EDL technologies.

The element which will not be covered at all by the ExoMars mission is the final propulsive descent phase, the hazard avoidance during this descent and the ultimate ‘soft’ landing. It is this phase which has been identified within the Aurora Programme as a key element around which to focus the development of future technologies. As will be seen, this is not purely in the preparation for MSR but also the applicability of these technologies, independently of entry and parachute descent, to other more near term exploration opportunities.

#### **4. THE ‘NEXT’ MISSION OPPORTUNITY**

In the current planning of the Aurora Programme the ExoMars mission is foreseen to launch in 2013, and the MSR mission is envisioned as no earlier than the 2020 timeframe – being largely driven also by the plans of international partners. This window between the two missions is regarded by ESA as an opportunity which can be used to implement a set of intermediate exploration goals – namely science in support of exploration and the demonstration of key technologies for MSR – through an exploration mission. This opportunity, termed Next Exploration Science and Technology mission (NEXT for short), is the current focus of preparations within Aurora beyond ExoMars.

The two main candidates for the technology demonstration to be performed through the NEXT mission are soft-landing with hazard avoidance, and autonomous rendezvous. It is these capabilities which drive to a certain extent the scientific objectives which can be envisaged within the different options for the NEXT mission. Considering in more detail the soft-landing option, it is clear that one of the main candidates for such a mission would be a lunar landing, during which many of the technologies required in the terminal descent of MSR might be demonstrated. The mission options for NEXT will be discussed in more

detail in the last chapter, however the preparation for such a landing demonstration mission is a key element in driving the development of technologies within the Core Programme.

### **5. TECHNOLOGY DEVELOPMENT**

Focusing specifically on soft-landing technologies, a development approach has been set up and is being implemented which builds on the past heritage of European lander technologies and which is aimed at the preparation for a NEXT mission demonstrating soft-landing with hazard avoidance. In terms of phasing of these developments, the aim is to have an autonomous soft-landing system at a technology readiness level (TRL) of 6 by the beginning of Phase B of the NEXT mission. In other words this means to have a full landing system tested in a ‘relevant environment’. In order to achieve this goal, the components of the landing system have been broken down into distinct elements which are currently undergoing specific development, and which will gradually be integrated into a single system.

#### **5.1 Tools and Testbeds**

In the development of critical technologies for landing, one of the key elements to be considered are the facilities which are required in order to verify the functionality, performance and operation of the various components. One of the key on-ground testbeds being developed within Europe is the Precision Landing GNC Test Facility (PLGTF), which is composed of an autonomous helicopter platform supported by dedicated electronics allowing it to simulate planetary lander trajectories and so present representative terrains to various GNC sensors (e.g. vision-based cameras, LIDAR).

Foreseen to be deployed in the Moroccan desert this facility would enable the verification of the functional performance of both the sensors themselves as well as the navigation algorithms employed to interpret the information received by the sensors. With the enhancement of the helicopter platform, the information received by the sensors will be used in a closed-loop GNC system in order to ‘command’ the helicopter as if it were a landing platform performing a descent to a planetary surface. A dynamic emulator will translate the commands of the autonomous GNC system into inputs to the helicopter’s flight control system in order to accurately represent the effects of the control.

In addition to this hardware testbed, tools are being developed to aid in the design of EDL systems through simulation. The High Fidelity End-to-End EDL Simulator will enable a comprehensive and complete treatment of the EDL system from a very early phase in mission design. Using this tool will allow for a more optimal design process and will help guide the development and evaluation of EDL concepts for the exploration missions of the future.

Crossing the boundary between software simulation and the testing of GNC hardware is the development of the Planetary and Asteroid Scene Generation Utility (PANGU: University of Dundee, UK). This tool which is being further enhanced within the Aurora Core Programme, has already been used to generate representative planetary surface terrains for the testing of various GNC algorithms. In particular the identification and tracking of feature points, and the identification of surface hazards. More than just a pure software tool, PANGU is also capable of supplying ‘real-time’ image information direct to hardware prototypes of navigation sensors (i.e. bypassing the optical head elements).

## 5.2 On-Board Navigation Systems

For a planetary lander, its on-board navigation system represents its eyes and its ability to process what it ‘sees’. The types of navigation sensors which are foreseen for future planetary lander applications fall generally into two categories: vision-based systems and LIDAR-based systems.

Vision-based camera technology has achieved a significant level of development within Europe, specifically with the development of the NPAL (Navigation for Planetary Approach and Landing) camera. Such a vision-based system processes optical images received in such a way as to extract from these images information on the lander’s relative position and motion with respect to the surface, as well as information on the characteristics of the surface itself. These surface terrain characteristics can be used to identify and avoid potential landing hazards such as boulders and large surface slopes.

LIDAR-based systems operate in a slightly different way, by building up digital elevation maps (DEM) of the surface terrain from the returned signal of a laser

pulse. These DEMs can then be used to extract similar information to the vision-based case but using somewhat different processing algorithms. The LIDAR option has the advantage of being independent of lighting or to some degree dust conditions, compared to vision-based systems, however implementing a lightweight LIDAR system for planetary lander applications remains a challenge.

Within the Aurora Core Programme, it is foreseen to pursue both vision and LIDAR based navigation sensor technologies in order to allow future mission flexibility and robustness. The focus will be on maturing the existing breadboard developments up to engineering model level, in part through campaigns of testing on-board the PLGTF. Progressively the navigation systems will be integrated into an overall landing GNC system, with a landing demonstration mission on the Moon as the driving mission objective.

## 5.3 System Development

While focused development will continue on navigation sensors and landing testbeds and tools, the overall challenge of development of the entire soft-landing system will also be addressed. Work has already been performed in considering the GNC system as a whole, based on both vision and LIDAR sensor navigation information. Addressing the particular challenges of guidance and control during the EDL phase will be performed in the activity Robust EDL Guidance and Control Techniques.

The results of the specific activities on end-to-end guidance and control will be integrated through the Scalable EDL GNC & Avionics System Demonstrator, along with the then developed and tested navigation systems (i.e. vision and LIDAR based).

In addition to the GNC elements of the soft-landing system, of course the physical platform must also be considered. This includes the touchdown system (e.g. landing legs) as well as the all important propulsion elements needed to control the descent. Considering first the landing legs, it is foreseen to develop a landing system testbed which includes a full set of landing legs and investigates the critical aspects of the final touchdown.

From a propulsion standpoint, the development of this key component will be driven by the outcomes of the ongoing mission concept studies. This is important in

order to best focus the resources needed for propulsion system development. Best use of existing European propulsion systems will be employed in this development.

## **6. NEXT MISSION PREPARATION**

The NEXT mission itself is still currently in the conceptual phase, with several concepts under evaluation. This work is being performed through a series of Pre-Phase A studies, implemented in the frame of the MSR Phase A2 activity. Three of these studies consider lunar lander missions aimed at demonstrating soft landing on the Moon, while a fourth considers the demonstration of autonomous rendezvous in Mars orbit.

Internal studies are also being carried out to investigate alternative mission options which might represent NEXT candidates. These represent the results of a Call for Ideas which collected proposals for scientific investigations which might be coupled with the demonstration of key capabilities for exploration.

Once completed, the full range of NEXT mission concept studies will be considered and evaluated together. Based on this evaluation and the consultation with the participating states of Aurora, up to two NEXT mission concepts will be selected to proceed to a Phase A study level. It should be noted that in defining the scope of the Phase A studies, some elements of the mission concepts already studied may be brought together in order to have the best combination.

## **7. CONCLUSION**

Within the Aurora mission roadmap the NEXT mission represents a key component in both the development of technologies and capabilities for MSR as well as carrying out specific exploration related scientific objectives. Indeed the NEXT mission itself is the driving element behind many of the technology development activities currently ongoing and planned within the Aurora Core Programme. Building on the existing European heritage in specific areas such as GNC, the development approach will focus on preparing key subsystems in time for implementation within future NEXT mission phases. Based on this integrated effort in both technology and mission system design, Europe hopes to demonstrate key technologies for MSR, as well as other exploration missions, in the intermediate timeframe.